STATISTICAL DISTRIBUTION OF THE FORMATION OF COMPACT OBJECTS IN THE MILKY-WAY GALAXY

By

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Abstract

The issue of galactic dynamism and structure is one of the top astrophysical research area. There is a progress both theoretically and observationally. Here, we examined one of the standard statistical approach called the initial mass function to population density to determine the population of newly formed compact objects in the Milky-Way galaxy. To this model we imposed an oversimplifying condition where the formation region is as a system assumed to be of spherical symmetry with falling density outward radially. The result is just in agreement with observation. But here we questioned the existing models are so oversimplified to be further developed.

Acknowledgements

This thesis marks the final steps of my formal education, since first starting primary school 20 years ago. Many people - family, friends and colleagues - have supported me on this incredible journey and I would like to take this opportunity to show my appreciation.
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Chapter 1

General Introduction

1.1 Background Rationale

Stellar evolution is a process by which star changes during its life time. Depending on the mass of the star, its life time ranges from a few million years for most massive stars to trillion years for the least massive ones, which is considerably a longer age than the age of the universe. However, on human timescales, most stars do not appear to change at all, but if they were to be looked for billions of years, they would have been seen how they are being born, age, and finally die. One of the primary factors determining how a star evolves is its mass. Depending on its mass on the main sequence evolution, the end product of the evolution is a collapsed star commonly known as compact object. This compact object is either a quantum degenerate pressure star that supports itself against gravity from further collapse or an eventually completely collapsed star commonly known as Black hole (BH). As the current astrophysical understanding implies low mass star (on the main sequence), of the order of our sun ends its evolutionary stage forming a compact object called White Dwarf (WD) which supports itself by quantum degenerate electron pressure. Even though the WD cannot radiate through nuclear reaction it evolves in radiating the stored thermal pressure for a long period of time, more than the present age of the universe. However, high mass star (on the main sequence) ends its evolutionary stage by forming either very high mass compact object called black hole (BH) or low mass compact object called neutron star. The details of the review can be referred from the classical books, for eg. [23], [3].

As literatures indicate that these special stellar evolutionary end products are major area of research in astrophysics. Amongst the many reasons, their extreme conditions in the vicinity of these objects lead to a variety of unusual phenomena such as high energy X-ray and gamma-ray radiation, high frequency oscillations, and relativistic jets. The objects are often extra ordinarily luminous and affect their surroundings to a much greater extent than one might guess from their small sizes.

Also, recent studies show that these objects, especially the class of supermassive black holes affect cosmic structure on scales by releasing streams of relativistic jets. At the same time, compact objects are of interest in their own right. The density inside a neutron star is greater than nuclear density, and the magnetic field is far greater than anything we can generate on Earth. A black hole is even more extreme. However, on the theoretical ground where and how to locate these objects need further study.

The physics of compact objects is very important in studying the hosting galaxies, local globular clusters. However, the observational capabilities and theoretical modelings need careful pull of physics together and relevant parameters. To this, end though there is a great progress in both, yet in both there is a great deal of limitations that need to research and develop. For example, within the limitation of concrete mathematical modeling of stellar evolution, the approximations we use in statistical modeling itself is full of incompleteness [14], [2].

Motivated by this background issue we are interested to study the statistical distribution of compact objects how they are being formed in our own Milky-Way galaxy.

1.2 Statement of the Problem

The astrophysical and astro-observation of the end products of stellar evolution is so important to understand formation, structure and dynamism over wide range of environments and phenomena include our Milk-Way and other galaxies. But a number of issues about the compact objects themselves remain unresolved. The observational capabilities and theoretical modelings need careful pull of physics together and relevant parameters to develop and use. To this end, though there is a great progress in both, yet in both there is a great deal of limitations that need to research and develop. Even, within the current limitations of concrete mathematical modeling of stellar evolution, the statistical modeling approximations used to study these compact objects populations itself is full of incompleteness.

Research Questions

- What is the astrophysical relevant of compact objects?
- How do the compact objects are distributed in Milky-Way galaxy?
- What astrophysical phenomena are relevant to study the compact objects and hence their distribution?
- What is the relationship between the newly formed compact object and its evolutionary history?

1.3 Objective

1.3.1 General Objective

To study the statistical distribution of the formation of compact objects in the Milky-Way galaxy.

1.3.2 Specific objectives

- To describe how compact objects are being distributed in their early formation.
- To explain the role of compact objects in astrophysical systems like evolution of galaxies, universe, etc.
- To review and comment on the astrophysical relevant of compact objects.
- To obtain the relationship between the newly formed compact object and its evolutionary history.

1.4 Methodology

The general method is to work out on compact object distribution theoretical models for White Dwarfs, Neutron stars, Black holes, and other void distributions where standard physics of such objects is taken into consideration to do the statistics with simplifying boundary conditions. Mainly, we assumed the initial mass function correlation to number density. On top of this we also assumed the luminosity function correlation to radial distance from the core of the formation system. Then, observational data extracted from observation (remote observatories, provided internationally like from Sloan Digital Sky Survey (SDSS), etc.) is used to analyse the results to conclusion.

1.5 Limitation

Due to server capacity and duration, we are limited to reduce data from virtual observatories.

Chapter 2

Literature Review

The global properties of compact objects (COs) in the Milky Way (MW) provide crucial information on the star formation history of the Galaxy as well as on stellar evolution. Broadly speaking, stars born with mass $M < 8M_{\odot}$ evolve into white dwarfs (WDs), those of $M \simeq 8 - 20M_{\odot}$ evolve into neutron stars (NSs), and those above $20M_{\odot}$ turn into black holes [24], though stars between $M \simeq 120 - 250M_{\odot}$ may undergo a pair instability supernova that leaves no remnant. Aside from systems that have undergone mergers or left the Galaxy due to BH kicks, the number of compact remnants quantifies past star formation. The localization of COs within a galaxy may also be indicative of the progenitor's formation conditions. The mass distributions, orbital properties and/ or proper motion of the COs can inform us on stellar evolution and explosion mechanisms.

The current ($z = 0$) population of BHs is particularly important as BHs evolve from the most massive stars, whose short lives mean that we can only directly observe the population that formed within the last 20 Myr. In particular, BHs provide unique information on the detail mass function of massive stars, which are key drivers of galactic evolution through chemical enrichment, stellar winds, ionizing radiation and their final explosions [4].

Unfortunately, the inventory of stellar mass black holes in the MW is far from complete. So far, the only confirmed systems are found in X-ray binaries, where the BHs manifest themselves through accretion of material from a companion star. So far, however, no BH has been observed in a binary with another compact object in the MW.

Similarly, there have been no firm detections of stellar mass BHs without a stellar companion in the MW. Such black holes are not expected to emit electromagnetic radiation unless they are accreting from a dense environment.

Two astronomy students from Leiden University have mapped the entire Milky Way in dwarf stars for the first time. They showed that there are a total of 58 billion dwarf stars, of which 7% reside in the outer regions of our galaxy. This result is the most comprehensive model ever for the distribution of these stars. The findings appear in a new paper in Monthly Notices of the Royal Astronomy Society.

The Milky Way, the galaxy we live in, consists of a prominent, relatively flat disc with closely spaced bright stars, and a halo, a sphere of stars with a much lower density, around it.

The galaxy is not a new discovery. It stood out to us because of the remarkable contrast between its appearance in Dragonfly images and Sloan Digital Sky Survey (SDSS) data. In SDSS it appears as a collection of point-like sources. Intrigued by the likelihood that these compact sources are associated with the low surface brightness object. We also observe the galaxy with the Hubble Space Telescope (HST). Fig.2.1 Shows HST/ACS image of NGC1052-DF2. Hubble Space Telescope imaging of NGC1052-DF2 was obtained 2016 November 10, using the Advanced Camera

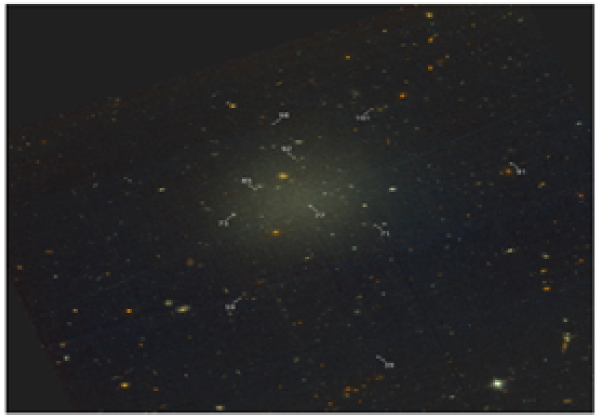

Figure 2.1: HST/ACS image of NGC1052-DF2. Hubble Space Telescope imaging of NGC1052-DF2 was obtained 2016 November 10, using the Advanced Camera for Surveys (ACS). Ten spectroscopically-confirmed luminous compact objects are marked.

for Surveys (ACS). Ten spectroscopically-confirmed luminous compact objects are marked.

A color image generated from the HST V_{606} and I_{814} data is shown in Fig.1.1. The galaxy has a striking appearance. We conclude that there is indeed a population of compact, luminous objects associated with NGC1052-DF2. Images of the compact objects and their locations are marked on Fig.1.1.

The SDSS addresses fascinating, fundamental questions about the universe. With the survey, astronomers will be able to see the large-scale patterns of galaxies: sheets and voids through the whole universe. Scientists have many ideas about how the universe evolved, and different patterns of large-scale structure point to different theories. The Sloan Digital Sky Survey will tell us which theories are right - or whether we will have to come up with entirely new ideas. Fig.2.2 Shows the large-scale patterns of galaxies.

Figure 2.2: The large-scale patterns of galaxies.

The SDSS will make the largest map in human history. It will give us a three-dimensional picture of the universe through a volume one hundred times larger than that explored to date. The SDSS will also record the distances to 100,000 quasars, the most distant objects known, giving us an unprecedented hint at the distribution of matter to the edge of the visible universe.

2.1 Black Holes

A gaggle of black holes has been found clustered around the center of our home galaxy, the Milky Way and the discovery hints at a much larger population of black holes hidden across the galaxy. The discover offers a new test bed for understanding the ripples in space-time known as gravitational waves.

For years, scientists have known that a monster black hole sits in the middle of the galaxy. Sagittarius A^* (Sgr A^*), the compact object, is more than four million times as massive as our Sun, but it's packed into a region of space no bigger than the distance between us and our star.

2.2 Neutron Stars in our Galaxy

Neutron stars in isolation or as companions of compact objects can appear as radio and/or X-ray pulsars. As of 2005, more than 1500 radio pulsars have been detected in large radio surveys and about 150 neutron stars are known as X-ray sources.

Neutron stars are thought to be born in type II supernovae. The typical event rate for such supernovae in spiral galaxies is of the order of one event every 50-100 years, though the historical event rate in our own Galaxy is somewhat short of this number due to various reasons. This means that our Galaxy is populated by at least a few hundred million neutron stars. Since the lifetime of a typical pulsar is only a few million years, we estimate to have about 10,000 active radio pulsars in our Galaxy [27].

Of these objects, only some fraction is visible due to the lighthouse effect. This demonstrates that the total number of detectable pulsars will be in the range of a few thousand objects for the entire Galaxy, depending somewhat on the topology of the magnetosphere of neutron stars. Dead pulsars will live forever as cooling rockets when flying through the Galaxy. The neutron star RX J1856-37 recently detected by HST is an example of such a flying graveyard. It is located at a distance of 200 light-years and moves with a speed of 100km/s through space. Its surface temperature is about 700,000 K. Similar to white dwarfs, we can distinguish between three types of neutron stars:

Thermal emission from isolated neutron stars: Observations of isolated neutron stars (or neutron stars in quiescent X-ray binaries) are extremely important in fundamental physics, as thermal emission from the surface of a neutron star carries signatures of its gravitational field, which may be used to infer its mass and radius.

Detection of absorption lines corresponding to elements on the neutron star atmosphere and measurement of their gravitational redshift would provide rather accurate data. From the gravitational redshift at the surface of the neutron star, the ratio between its mass and radius may be measured, providing a very strong constraint on neutron star models. Such models give physics an experimentally testable handle on properties of matter at (supra-)nuclear densities.

Rotation-powered neutron stars (radio pulsars): Neutron stars rotate very rapidly, up to 600 times per second. But how are they spinning when they are born? They may be born rotating very fast, with periods comparable to a millisecond (although evidence is ambiguous). After that, they spin down ever after because of magnetic torques. This seems to be supported by the fact that some of the youngest pulsars, such as the Crab pulsar (33ms) and the Vela pulsar (80ms) have unusually short periods. After a pulsar is born, its magnetic field will exert a torque and slow it down, with typical spin-down rates of 10-13 s/s for a young pulsar like the Crab. Neutrons stars were discovered in 1932, and very shortly afterward (in 1934) a suggestion was made by Walter Baade and Fritz Zwicky that neutron stars were formed in supernovae. A number of other pulsars were discovered, including one in the Crab Nebula, site of a famous supernova in the year 1054 that was observed by Chinese, Arabic, and North American astronomers (but not recorded, as far as we know, by Europeans). Within a year or so of the initial discovery, it became clear that:

- pulsars are fast, with periods known in 1968 from 0.033seconds (the Crab pulsar) to about 2 seconds,
- the pulsations are very regular, with a typical rate of change of only a second per 10 million years, and

- over time, the period of a pulsar always increased slightly.

Accretion-powered neutron stars in X-ray binary systems: Not all neutron stars are destined to lead a life of isolation. Some of them are born in binaries that survive the supernova explosion that created the neutron star, and in dense stellar regions such as globular clusters some neutron stars may be able to capture companions.In either case, mass may be transferred from the companion to the neutron star. However, since the neutron star is tiny, astronomically speaking, the gas has too much angular momentum to fall on the star directly and therefore orbits around the star in an accretion disk. Within the disk, magnetic or viscous forces operate to allow the gas in the disk to drift in slowly as it orbits, and to eventually reach the stellar surface. If the magnetic field at the neutron star's surface exceeds about $10^8 G$,then before the gas gets to the stellar surface the field can couple strongly to the matter and force it to flow along field lines to the magnetic poles. The friction of the gas with itself as it spirals in towards the neutron star heats the gas to millions of degrees, and causes it to emit X-rays [26].

2.3 Measuring Distance and Time: Redshift

Redshift is displacement of the spectrum of an astronomical object toward longer (red) wavelengths. It is generally attributed to the Doppler effect, a change in wavelength that results from the Milky Way Galaxy system, in which Earth is located, and that their redshifts increase proportionally with their increasing distance.

Since the early 1960s astronomers have discovered cosmic objects known as quasars that exhibit larger redshifts than any of the remotest galaxies previously observed.The extremely large redshifts of various quasars suggest that they are moving away from

Earth at tremendous velocities (i.e., approximately 90% the speed of light) and thereby constitute some of the most distant objects in the Universe.

The universe is expanding like a loaf of raisin bread rising in an oven. Pick any raisin, and imagine that it's our own Milky Way galaxy. If you place yourself on that raisin, then no matter how you look at the loaf, as the bread rises, all the other raisins move away from you. The farther away another raisin is from you, the faster it moves away. In the same way, all the other galaxies are moving away from ours as the universe expands. And because the universe is uniformly expanding, the farther a galaxy is from Earth, the faster it is receding from us.

The light coming to us from these distant objects is shifted toward the red end of the electromagnetic spectrum, in much the same way the sound of a train whistle changes as a train leaves or approaches a station. The faster a distant object is moving, the more it is redshifted. Astronomers measure the amount of redshift in the spectrum of a galaxy to figure out how far away it is from us. By measuring the redshifts of a million galaxies, the Sloan Digital Sky Survey will provide a three-dimensional picture of our local neighborhood of the universe.

Chapter 3

Introduction to Galaxy and Galaxy Evolution

3.1 Introduction to Galaxy

The major components of the universe are galaxies. There are hundreds of billions of galaxies in the Universe. These large-scale groups of stars are bound together by gravitational attraction. A typical galaxy is about 100,000 light-years in diameter and contains 100 billion stars. Therefore, galaxy is a component of our universe made up of gas and a large number (usually more than a million) of stars held together by gravity. When capitalized, Galaxy refers to our own Milky Way galaxy.

Astronomers estimate that there are between 50 billion and 1 trillion galaxies in the known part of the Universe. Two galaxies, the Large Magellanic Cloud and Small Magellanic Cloud, are the closest neighbors to the Earth's gravity, which is the Milky Way Galaxy. Even so, the Large and Small Magellanic clouds are 150,000 light - years away. Within 3 million light years of the Milky Way Galaxy are about 17 other galaxies. These galaxies, and the Milky-Way Galaxy collectively are called the Local Group [17].

Galaxies are huge collections of stars, dust and gas. They usually contain several million to over a trillion stars and can range in size from a few thousand to several hundred thousand light years across.

3.2 Types and Classification of Galaxies

Galaxies vary in size, structure, and luminosity, and, like stars, are found alone, in pairs, or in clusters.

In studying the vast number of galaxies, astronomers found that galaxies could be classified by shape into the three main types: spiral galaxy, elliptical galaxies, and irregular galaxy.

3.2.1 Spiral galaxies

One type, called a spiral galaxy, has a nucleus, or center, of bright stars and flattened arms of stars that spiral around the nucleus. The spiral arms contain millions of young stars, gas, and dust. Some spiral galaxies have a bar of stars that runs through the center. These galaxies are called barred spiral galaxies.

Spiral galaxies get their name from the shape of their disks, in which stars, gas and dust are concentrated in spiral arms that extend outward from the central nucleus of the galaxies.

Spiral galaxies have three main components: a bulge, disk, and halo. The bulge is a spherical structure found in the center of the galaxy. This feature mostly contains older stars. The disk is made up of dust, gas, and younger stars. The disk forms arm structures. Our Sun is located in an arm of our galaxy, the Milky Way. The halo of a galaxy is a loose, spherical structure located around the bulge and some of the disk. The halo contains old clusters of stars, known as globular clusters.

Spiral galaxies are classified into two groups, ordinary or normal, and barred spirals. The ordinary group is designated by S or SA, and the barred group by SB. In normal spirals the arms originate directly from the nucleus, or bulge, where in the barred spirals there is a bar of material that runs through the nucleus that the arms emerge from. Both of these types are given a classification according to how tightly their arms are wound.

Our Milky Way galaxy is an example of a spiral galaxy. Spiral galaxies are rich in gas and dust and have a high rate of star formation. Since spirals contain a high fraction of hot, young stars, they are often among the brightest galaxies in the universe.

If you look in to the night sky, you will see a cloudlike band of stars that stretches across the sky. Because of its milky appearance, this part of the sky is called the Milky Way. The Milky-Way is the disk of the Milky-Way galaxy. The Milky-Way galaxy is a spiral galaxy in which the sun is but one of billions of stars. Each stars seem to be moving toward the sun, while others seem to be moving away from it [1]. The Milky-Way galaxy has a diameter of about 100,000 light-years. At this nucleus, the galaxy is 2,000 light-years thick, with the sun located about 30,000 light-years from the center. The Milky-Way galaxy, like all spiral galaxies, rotates. The sun, which is located in one of the spiral arms, revolves around the center of the galaxy at a speed of 250km/s. At this speed, it completes one rotation in about 200 million years.

3.2.2 Elliptical galaxies

Galaxies of the second type vary in shape from nearly spherical to flattened disks. These galaxies are called elliptical galaxies. They are very bright in the center and do not have spiral arms. These galaxies have no young stars and contain very little dust and gas.

In general, elliptical galaxies are shaped like a spheroid, or elongated sphere. That is, roughly egg-shaped (ellipsoidal or ovoid). In the sky, where we can only see two of their three dimensions, these galaxies look like elliptical, or oval, shaped disks. The light is smooth, with the surface brightness decreasing as you go farther out from the center.

Elliptical galaxies are divided into eight subgroups: $E_0 - E_7$ depending on their elongation. E_0 ellipticals are nearly circular, while E_7 are highly elongated [19].

Elliptical galaxies are given a classification that corresponds to their elongation from a perfect circle, otherwise known as their ellipticity. The larger the number, the more elliptical the galaxy is. So, for example a galaxy of classification of E_0 appears to be perfectly circular, while a classification of E_7 is very flattened. The elliptical scale varies from E_0 to E_7. Elliptical galaxies have no particular axis of rotation.

Fig.3.1 Shows the Revised Hubble Sequence of Galaxies, also commonly known as the Hubble Tuning Fork.

Elliptical galaxies contain primarily old stars, and do not have much gas and dust. There is very little new star formation in these galaxies.

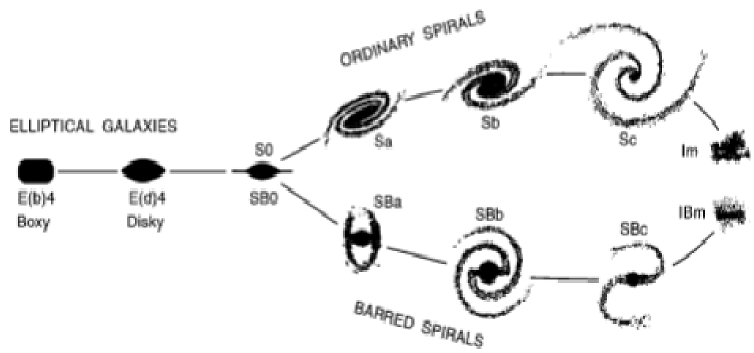

Figure 3.1: The Revised Hubble Sequence of Galaxies, also commonly known as the Hubble Tuning Fork.Credit: Kormendy & Bender [1996]

3.2.3 Irregular galaxies

The third type of galaxies, called an irregular galaxy, has no particular shape. They have no regular or symmetrical structure. Irregular galaxies tend to be smaller and fainter than other types of galaxies. Some astronomers think that either the stars in irregular galaxies are of low mass and cannot organize in to a regular pattern or they are the result of two galaxies colliding. Thus, the stars in an irregular galaxy are unevenly distributed throughout the galaxy.

Irregular galaxies have no particular shape (i.e. no specific shape). They are among the smallest galaxies and they contain a vast amount of gas and dust. As a result, they have a very high rate of star formation. The Large and Small Magellanic Clouds are examples of irregular galaxies.

Fig.3.2 Shows examples of the three main types of galaxies:spiral(left), elliptical (middle), and irregular (right).

The infrared emission from galaxies comes primarily from three sources:stars, interstellar gas, and dust. The emission from stars peaks in the near-infrared (1-3

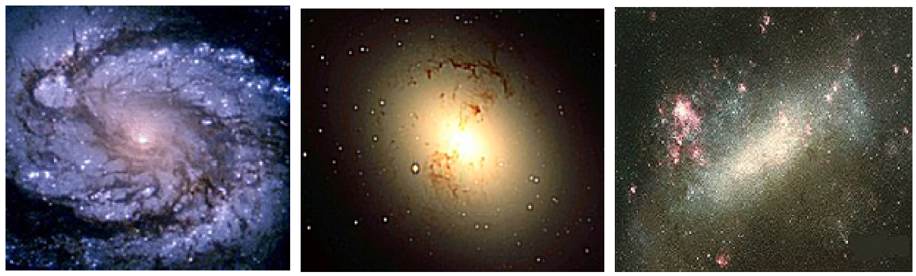

Figure 3.2: Examples of the three main types of galaxies: spiral(left), elliptical(middle), and irregular(right)

micrometers). Emission from atoms and molecules in interstellar gas makes up only a few percent of the infrared output of galaxies. The primary source of infrared radiation beyond 3 micrometers is thermal emission from dust grains heated by starlight. The brightest infrared galaxies are usually the ones which have a lot of dust(from star-forming regions for example). Spiral galaxies which are rich in gas and dust are strong infrared sources and are still forming new stars. About half of the luminosity of an average spiral galaxy is radiated at far-infrared wavelengths. Elliptical galaxies are faint in the infrared because they do not have much gas and dust [13].

3.3 Normal, Active and Dead Galaxies

3.3.1 Normal Galaxies

These are galaxies in which there is a low rate of star formation but high rate of star death (formation of compact objects). Milky Way galaxy is one example of normal galaxies.

For normal galaxies, we think of the total energy they emit as the sum of the emission from each of the stars found in the galaxy. A normal star is a fully Newtonian object.

3.3.2 Active Galaxies

In these type of galaxies, there is a very high rate of star formation and low rate of star death (i.e. low rate of formation of compact objects).

The light from most galaxies is just the sum of light from all of the stars within it, so like starlight, a galaxy's light is brightest at optical wavelengths and fainter at shorter and longer wavelengths.

But small fractions of galaxies are different; they are much brighter and produce more long- and short- wavelength emission. They are called active galaxies. They are galaxies with extremely violent energy release in their nuclei. Up to many thousand times more luminous than the entire Milky Way; energy released within a region approximately the size of our solar system!

Fig.3.3 Shows intensity of active, and normal galaxies at different wave lengths.

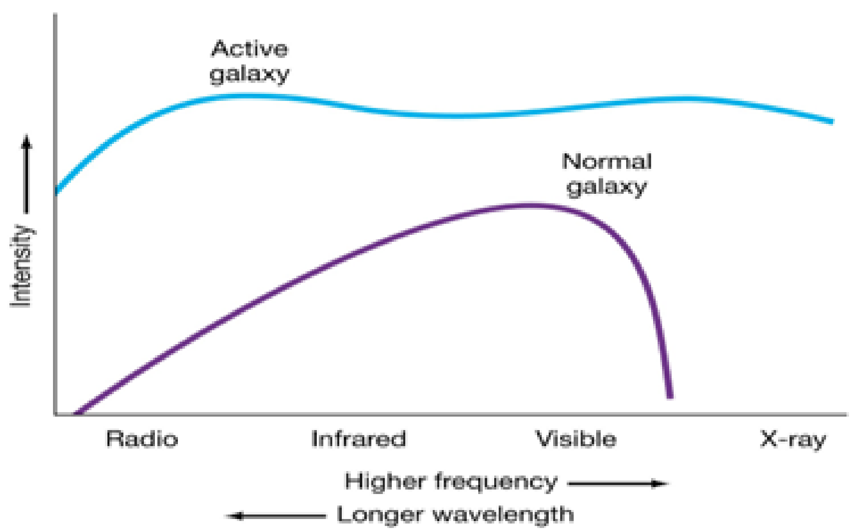

Figure 3.3: Intensity of active, and normal galaxies at different wave lengths.

Active galaxies are galaxies that have a small core of emission embedded at the center of an otherwise typical galaxy. This core is typically highly variable and very bright compared to the rest of the galaxy.

For normal galaxies, we think of the total energy they emit as the sum of the emission from each of the stars found in the galaxy, but in active galaxies, this is not true. There is a great deal more emitted energy in active galaxies than there should be and this excess energy is found in the infrared, radio, UV, and X-ray regions of the electromagnetic spectrum. The energy emitted by an active galaxy, AGN for short, is anything but normal. So what is happening in these galaxies to produce such an energetic output?

Fig.3.4 Shows an artist's concept of the central region of an active galaxy.

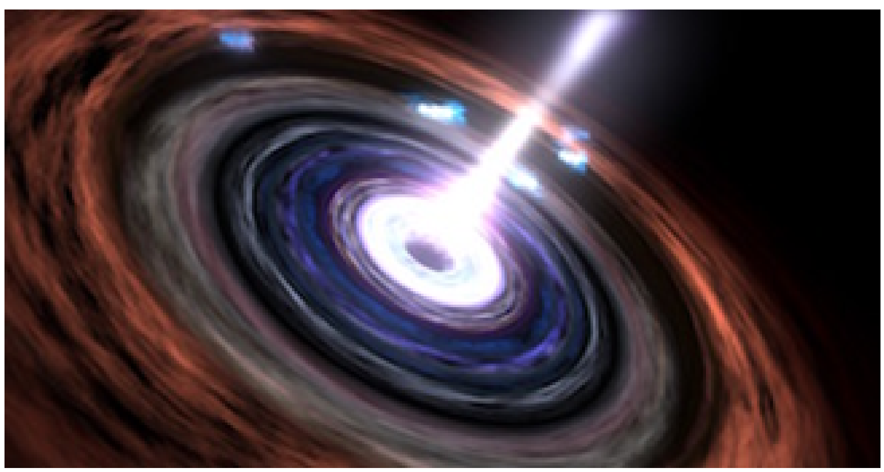

Figure 3.4: An artist's concept of the central region of an active galaxy. (Credit: NASA/Goddard Space Flight Center Conceptual Image Lab)

Most, if not all, normal galaxies have a supermassive black hole at their center. In an active galaxy, its supermassive black hole is accreting material from the galaxy's dense central region. As the material falls in toward the black hole, angular momentum will cause it to spiral in and form into a disk. This disk, called an accretion disk, heats up due to the gravitational and frictional forces at work.

Fig.3.5 Illustration shows the different features of an active galactic nucleus (AGN).

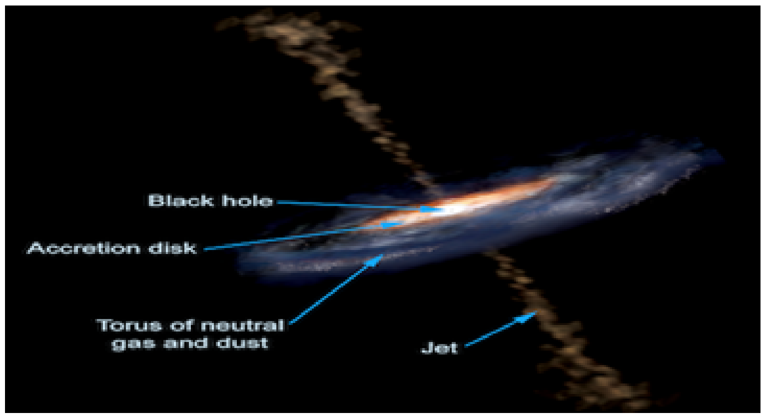

Figure 3.5: This illustration shows the different features of an active galactic nucleus (AGN). The extreme luminosity of an AGN is powered by accretion onto a supermassive black hole. Some AGN have jets, while others do not. (Credit: Aurore Simonnet, Sonoma State University)

The extreme luminosity of an AGN is powered by accretion onto a supermassive black hole. Some AGN have jets, while others do not.

In general, active galaxy is a galaxy that has exceptionally high luminosity and which radiates large amount of non-stellar radiation. The spectrum of radiation emitted by an active galaxy is very different from that of an ordinary galaxy, which shines with the combined light of its stars and nebulae. A galaxy is said to be 'active' if it generates substantial amounts of energy that is not produced by stellar evolution.

In most cases, this non-stellar emission appears to come from the very center of the galaxy. This central region of the galaxy is called the Active Galactic Nucleus or AGN.

The following properties are observed in active galaxies:

- An overall luminosity exceeding $10^{44} erg/sec$.
- A much higher output of X-ray, ultraviolet, infrared and radio radiation than a normal galaxy.
- A highly luminous and compact central core, known as AGN, which varies rapidly in brightness.
- Broad emission lines in its spectrum.
- Narrow jets of radiating matter emerging from the central core.
- Large scale clouds of radio-emitting material.

Observations of Active Galaxies

AGN are the most luminous long-lived sources in the universe, emitting strong radiation over the entire observable wave length range, from x-rays and γ -rays through long-wave length radio. A complete picture of AGN emission can be obtained by simultaneous multi wavelength observations over the entire spectral range.

Active galactic nucleus (AGN)is the central region of a galaxy that shows unusual energetic activity. It is a compact region at the center of a galaxy that has a much higher than normal luminosity over at least some portion of the electromagnetic spectrum with characteristics indicating that the luminosity is not produced by stars. Such excess non-stellar emission has been observed in the radio, microwave, infrared, optical, ultra-violet, X-ray and gamma ray wavebands. A galaxy hosting an AGN is called an "active galaxy". The radiation from an AGN is believed to result from the accretion of matter by a supermassive black hole at the center of its host galaxy.

Active galactic nuclei are the most luminous persistent sources of electromagnetic radiation in the universe, and as such can be used as a means of discovering distant objects; their evolution as a function of cosmic time also puts constraints on models of the cosmos.

The observed characteristics of an AGN depend on several properties such as the mass of the central black hole, the rate of gas accretion onto the black hole, the orientation of the accretion disk, the degree of obscuration of the nucleus by dust, and presence or absence of jets.

Numerous subclasses of AGN have been defined based on their observed characteristics; the most powerful AGN are classified as quasars. A blazar is an AGN with a jet pointed toward the Earth, in which radiation from the jet is enhanced by relativistic beaming.

Models of active galaxies also include a region of cold gas and dust, thought to be in the shape of a giant donut with the black hole and accretion disk nestled in the donut's hole. In about one out of ten AGN, the black hole and accretion disk produce narrow beams of energetic particles and ejects them outward in opposite directions away from the disk. These jets, which emerge at nearly the speed of light, become a powerful source of radio wave emission.

The properties of an active galaxy are determined by the black hole's mass, the rate of accretion onto the black hole, whether or not it has a powerful jet, and the angle at which we view the galaxy. Radio galaxies, quasars, and blazars are AGN with strong jets that can travel outward into large regions of intergalactic space. Some of the apparent differences between types of AGN are due to our having different orientations with respect to the disk. With blazars and quasars, we are looking down the jet.

Active galaxies are intensely studied at all wavelengths. Since they can change their behavior on short timescales, it is useful to study them simultaneously at all energies. X-ray and gamma-ray observations have proven to be important parts of this multi wavelength approach since many high-energy quasars emit a large fraction of their power at such energies. The X-rays in AGN originate from very near the black hole, so X-ray studies can provide scientists with unique insights into the physical processes occurring in the central engine. In addition, gamma-ray observations alone can provide valuable information on the nature of particle acceleration in the quasar jet and clues as to how the particles interact with their surroundings.

The term "Active Galactic Nucleus" (AGN) refers to the existence of energetic phenomena in the nuclei of galaxies that cannot be attributed directly to stars.

AGN are classified based (in large part) on their luminosity in different wavebands (especially the optical and radio).

Today, AGN are a major topic of astrophysical research, both observational and theoretical. AGN research encompasses observational surveys to find AGN over broad ranges of luminosity and redshift, examination of the cosmic evolution and growth of black holes, studies of the physics of black hole accretion and the emission of radiation from AGN, examination of the properties of jets and outflows of matter from AGN, and the impact of black hole accretion and quasar activity on galaxy evolution.

Models

For a long time it has been argued that an AGN must be powered by accretion of mass onto massive black holes (10^6 to 10^{10} times the Solar). AGN are both compact and persistently extremely luminous. Accretion can potentially give very efficient conversion of potential and kinetic energy to radiation, and as a result, it can provide the observed high persistent luminosity. Thus AGN-like characteristics are expected whenever a supply of material for accretion comes within the sphere of influence of the central black hole.

Accretion disc

In the standard model of AGN, cold material close to a black hole forms an accretion disc. Dissipative processes in the accretion disc transport matter inwards and angular momentum outwards, while causing the accretion disc to heat up. The radiation from the accretion disc excites cold atomic material close to the black hole and this in turn radiates at particular emission lines. A large fraction of the AGN's radiation may be obscured by interstellar gas and dust close to the accretion disc, but (in a steady-state situation) this will be re-radiated at some other waveband, most likely the infrared.

Relativistic jets

Some accretion discs produce jets of twin, highly collimated, and fast outflows that emerge in opposite directions from close to the disc. The direction of the jet ejection is determined either by the angular momentum axis of the accretion disc or the spin axis of the black hole. The jet production mechanism and indeed the jet composition on very small scales are not understood at present due to the resolution of astronomical instruments being too low. The jets have their most obvious observational effects in the radio waveband, where very-long-baseline interferometry can be used to study the synchrotron radiation they emit at resolutions of sub-parsec scales. However, they radiate in all wavebands from the radio through to the gamma-ray range via the synchrotron and the inverse-Compton scattering process, and so AGN jets are a second potential source of any observed continuum radiation.

Jets in Active Galaxies

Jets in active galaxies are signatures of energy supply via collimated beams of plasma from the galactic nucleus to the extended regions of emission. These jets, which occur across the electromagnetic spectrum, are powered by supermassive black holes in the centers of the host galaxies. Jets are seen on the scale of parsecs in the nuclear regions to those which power the giant radio sources extending over several mega parsecs [11]. Astrophysical jets, which appear as extended, collimated structures, are believed to be caused by outflows from compact objects. These are seen in a variety of situations. These include:

- Young stars and protostars, which become stars once the thermonuclear reactions in the stellar interiors start off;
- Active galactic nuclei (AGN) associated with supermassive black holes (SMBHs) which are located in the centers of galaxies and have masses ranging from about 10^7 to $10^{10} M_{\odot}$, where $M_{\odot}$ denotes the mass of the Sun;
- Binary stellar systems emitting at X-ray wavelengths where a collapsed or 'dead' star, such as a white dwarf, neutron star or black hole, accretes matter from its normal stellar companion;
- Gamma-ray bursts which are highly energetic and catastrophic events associated with the collapse of massive stars where jets may be directed towards us; and
- Jets from pulsars, which are rapidly rotating neutron stars emitting narrow beams of radiation.

3.3.3 Dead Galaxies

Galaxy Evolution

In these type of galaxies, there is a star formation but it is negligible when compared to that of active, and normal galaxies.

What makes a dead galaxy?

Galaxies are dynamic systems that continually accrete gas and convert some of it in to stars. They 'quench' their star formation and continually change their morphology, or shape. They are mainly two sorts - half are alive and half are dead galaxies. Alive Galaxies are gas-rich galaxies getting a supply of fresh hydrogen gas from the cosmic web. As this cools and falls into dark matter halos, it turns into a disk that then can cool even further and eventually fragment into stars. There are some galaxies which are not nearly so active and have lost their supply of gas and therefore do not form stars. The basic division of galaxies into star-forming blazing in blue light and on other hand is dead galaxies covered in red light. These galaxies have turned into spheroidal or football shaped as their stars move on far more in unordered orbits.

A dead galaxy does not mean it has stopped forming stars. Since the reservoirs of any galaxy are enormous, and conversion of gas is a very slow process, a spiral galaxy could go on for a while looking alive. But actual star formation declines over several billion years.

Elliptical galaxies are dead galaxies walking. They have used up all their reserves of star-forming gas and left with long lasting stars.

Compact Objects in Astrophysics

The Universe is very big and it is comprised of many different objects. Stars, planets, comets, asteroids, dust, and many other objects populate the universe. Stars are the most researched part of the universe because there are billion and billions of stars. Each star depending on its initial mass will either end up as a white dwarf, neutron star, or black hole.

Before proceeding, we review some concept related to compact stars and some necessary formalism for hydrostatic equilibrium equations in General Relativity. Stars are generally in a state of almost complete mechanical equilibrium, which allows us to derive and apply the important virial theorem. We consider the basic stellar timescales and see that most (but not all) stars are also in a state of energy balance called thermal equilibrium [25].

Assuming spherical symmetry, which is promoted by self-gravity and is a good approximation for most stars; the equation of motion for a gas element inside the star is given by:

$$\frac{\partial^2 r}{\partial t^2} = -\frac{Gm}{r^2} - \frac{1}{\rho}\frac{\partial p}{\partial r} \tag{3.3.1}$$

This is a simplified from of the Navier-Stokes equation of hydrodynamics, applied to spherical symmetry. Writing the pressure gradient $\frac{\partial p}{\partial r}$ in terms of the mass coordinate m by substituting in the eqn. (3.3.1), the equation of motion is:

$$\frac{\partial^2 r}{\partial t^2} = -\frac{Gm}{r^2} - 4\pi r^2\frac{\partial p}{\partial m} \tag{3.3.2}$$

Hydrostatic equilibrium (HE): The great majority of stars are obviously in such long-lived phases of evolution that no change can be observed over human lifetimes. This means there is no noticeable acceleration, and all forces acting on a gas element inside the star almost exactly balance each other. Thus most stars are in a state of mechanical equilibrium which is more commonly called hydrostatic equilibrium (HE).

The state of hydrostatic equilibrium, setting $a = \ddot{r} = \frac{\partial^2 r}{\partial t^2} = 0$ in eqns.(3.3.1) and (3.3.2), yields the second deferential equation of stellar structure:

$$\frac{\partial p}{\partial r} = -\frac{Gm}{r^2}\rho \tag{3.3.3}$$

Or

$$\frac{\partial p}{\partial m} = -\frac{Gm}{4\pi r^4} \tag{3.3.4}$$

Most stars will eventually come to a point in their evolution when the outward radiation pressure from the nuclear fusions in its interior can no longer resist the ever-present gravitational forces. When this happens, the star collapses under its own weight and undergoes the process of stellar death. For most stars, this will result in the formation of a very dense and compact stellar remnant, also known as a compact star. Compact stars have no internal energy production, but will- with the exception of black holes usually radiate for millions of years with excess heat left from the collapse itself [6].

Classes of Compact Objects

Compact stars form the end point of stellar evolution. A star shines and thus loses its nuclear energy reservoir in a finite time. When a star has exhausted all its energy (which is called a stellar death), the gas pressure of the hot interior can no longer support the weight of the star and the star collapses to a denser state - a compact star. One could see the compact stars, such as the white dwarf and the neutron star, as a solid state as opposed to the gaseous interior of all other stars. In contrast to this, the interior of a black hole is very enigmatic. Its surface is formed by a kind of semi permeable membrane forbidding any classical emission from its surface. The very source of the gravitational field of black holes is a kind of curvature singularity, which is hidden behind this membrane. It is expected that quantum effects will smooth these singular mass currents in the center of a rotating Black hole.

The visible Universe therefore contains at least 100 billion super massive black holes. Only about 100,000 of these objects have now been detected as quasars and only about 50 as mass centers of nearby galaxies. Black holes of varying mass are also thought to be the driver behind gamma busters [7].

As a class of astronomical objects, compact objects include white dwarfs, neutron stars and black holes. As the endpoint states of stellar evolution, they form today fundamental constituents of galaxies. In the form of super massive black holes, these objects also live in practically every center of a galaxy. Our Galaxy harbors a black hole of 3.8 million solar masses, but the center of in the Virgo cluster encloses a black hole of three billion solar masses. These super massive black holes are the most extreme objects found in the Universe. While neutron stars and stellar mass black holes mainly entered astrophysical research means of their radio and X-ray emission, white dwarfs had already been detected 100 years ago by their optical emission.

Compact stars,white and neutron stars,are the ashes of luminous stars. A black hole is the fate of the most massive stars - an inaccessible region of space-time in to which the star falls at the end of its luminous phase. White Dwarf stars are the size of the Earth but have mass comparable to that of the Sun. Neutron stars have density comparable to that of nuclei.

Fig.3.6 Shows compact objects in binary Systems. Compact stars are formed in

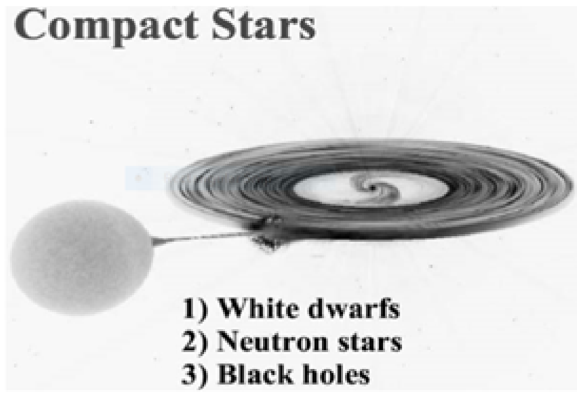

Figure 3.6: Compact Objects in binary Systems. Compact stars are formed in stellar evolution and often live in a binary system, surrounded by gas rings formed by mass overflow from its companion star. Source:Max Comenzind

stellar evolution and often live in a binary system,surrounded by gas rings formed by mass overflow from its companion star.

A study of compact objects:white dwarfs, neutron stars, and black holes begins when normal stellar evolution ends. All these objects differ from normal stars in at least two aspects:

- They are not burning nuclear fuel, and they cannot support themselves against gravitational collapse by means of thermal pressure. Instead white dwarfs are supported by the pressure of the degenerate electrons, and neutron stars are largely supported by the pressure of the degenerate neutrons and quarks.

Only black holes represent completely collapsed stars, assembled by mere self-gravitating forces.

- The second characteristic property of compact stars is their compact size. They are much smaller than normal stars and therefore have much stronger surface gravitational fields.

- Often compact objects carry strong magnetic fields, much stronger than found in normal stars.

All of these objects have a mass relative to their radius, giving them very high density. Now let's see WDs, NSs and BHs as follows:

1. White Dwarfs (WDs)

   White dwarf stars, compact objects with extremely high interior densities, are the most common end product in the evolution of stars.

   White dwarfs mark the evolutionary endpoint of low to intermediate mass stars like our Sun. Fusion processes in the cores of these stars cease once the helium has been converted to carbon, since the contracting carbon core does not reach a high enough temperature to ignite. Instead, it contracts until it squeezes all of its electrons into the smallest possible space they can occupy. The resulting electron pressure arises due to quantum mechanical effects, and stops gravity from compressing the core further. A white dwarf is therefore supported by the pressure of electrons rather than energy generation in its core. Fig.3.7 Shows white dwarf formed at the end of stellar evolution.

   Once the core has stopped contracting, the white dwarf has a temperature of over 100,000 Kelvin and shines through residual heat. These young white dwarfs

Figure 3.7: White dwarf formed at the end of stellar evolution.

typically illuminate the outer layers of the original star ejected during the red giant phase, and create a planetary nebula. This continued radiation from the white dwarf, coupled with the lack of an internal energy source, means that the white dwarf begins to cool. Eventually, after hundreds of billions of years, the white dwarf will cool to temperatures at which it is no longer visible and it will become a black dwarf.

White dwarf stars are extreme objects that are roughly the same size as the Earth. They have densities typically around $10^9 kg/m^3$(the Earth has a density of around $5X10^3 kg/m^3$) meaning that a teaspoon of white dwarf material would weigh several tonnes.

A white dwarf, also called a degenerate dwarf, is a stellar core remnant composed mostly of electron-degenerate matter. A white dwarf is very dense: its mass is comparable to that of the Sun, while its volume is comparable to that of Earth. A white dwarf's faint luminosity comes from the emission of stored thermal energy; no fusion takes place in a white dwarf wherein mass is converted to energy. The nearest known white dwarf is Sirius B, at 8.6 light years, the smaller component of the Sirius binary star. There are currently thought to be eight white dwarfs among the hundred star systems nearest the Sun. The unusual faintness of white dwarfs was first recognized in 1910 [8].

White dwarfs are thought to be the final evolutionary of stars whose mass is not high enough to become a neutron star whose, that of about 10 solar masses.This includes over 97% of the other stars in the Milky Way. Usually, white dwarfs are composed of Carbon and Oxygen.

The material in a white dwarf no longer undergoes fusion reactions, so the star has no source of energy. A s a result, it cannot support itself by the heat generated by fusion against gravitational collapse, but is supported only by electron degeneracy pressure, causing it to be extremely dense.

A white dwarf is very hot when it forms, but because it has no source of energy, it will gradually cool as it radiates its energy. This means that its radiation, which initially has a high color temperature, will lessen and redden with time. Over a very long time, a white dwarf will cool and its material will begin to crystallize, starting with the core. The star's low temperature means it will no longer emit significant heat or light, and it will become a cold black dwarf. Because the length of time it takes for a white dwarf to reach this state is calculated to be longer than the current age of the universe (approximately 13.8 billion years), it is thought that no black dwarfs yet exist. The oldest white dwarfs still radiate at temperatures of a few thousand kelvins.

A white dwarf is what stars like our Sun become when they have exhausted their nuclear fuel. Near the end of its nuclear burning stage, such a star expels most of its outer material (creating a planetary nebula), until only the hot core remains, which then settles down to become a very hot $T < 100,000K$ young white dwarf. Since a white dwarf has no way to keep itself hot unless it is accreting matter from a nearby star (as a cataclysmic variable), it cools down over the course of the next billion years. Many nearby, young white dwarfs have been detected as sources of soft X-rays (i.e. lower-energy X-rays); recently, soft X-ray and extreme ultra violet observations have become a powerful tool in the study of the composition and structure of the thin atmosphere of these stars.

A typical white dwarf is half as massive as the Sun, yet only slightly bigger than the Earth. This makes white dwarfs one of the densest forms of matter, surpassed only by neutron stars. Once a star is degenerate, gravity cannot compress it anymore because quantum mechanics tells us there is no more available space to be taken up. A white dwarf survives therefore, not by internal combustion, but by quantum mechanical principles that prevent its complete collapse. Such degenerate matter has other unusual properties; for example, the more massive a white dwarf is, the smaller it is, contrary to what is observed for normal stars. This is because the more mass a white dwarf has, the more its electrons must squeeze together to maintain enough outward pressure to support the extra mass [12].

With a surface gravity of 100,000 times that of the Earth, the atmosphere of a white dwarf is very strange. The heavier atoms in its atmosphere sink and the lighter ones remain at the surface. Some white dwarfs have almost pure hydrogen or helium atmospheres, the lightest of elements. Also, the very strong gravity pulls the atmosphere close around it in a very thin layer.

Since white dwarf stars glow just from residual heat, the oldest white dwarfs will be the coldest and thus the faintest. By searching for faint white dwarfs, one can estimate the length of time the oldest white dwarfs have been cooling. The luminosity function of white dwarfs at low luminosities, and especially the position of its cutoff, provides important information about the age of the Galactic disk.

2. Neutron Stars (NSs)

White dwarfs and neutron stars are stellar objects with masses comparable to that of our sun.

Neutron stars are created when giant stars die in supernovas and their core collapse, with the protons and electrons essentially melting into each other to form neutrons.

Neutron stars comprise one of the possible evolutionary end-points of high mass stars. Once the core of the star has completely burned to iron, energy production stops and the core rapidly collapses, squeezing electrons and protons together to form neutrons and neutrinos. The neutrinos easily escape the contracting core but the neutrons pack closer together until their density is equivalent to that of an atomic nucleus. At this point, the neutrons occupy the smallest space possible (in a similar fashion to the electrons in a white dwarf) and, if the core is less than about 3 solar masses, they exert a pressure which is capable of supporting a star. For masses larger than this, even the pressure of neutrons cannot support the star against gravity and it collapses into a stellar black hole.

A star supported by neutron degeneracy pressure is known as a 'neutron star', which may be seen as a 'pulsar' if its magnetic field is favourably aligned with its spin axis.

Neutrons stars are extreme objects that measure between 10 and 20 km across. They have densities of $10^{17} kg/m^3$ (the Earth has a density of around $5X10^3 kg/m^3$ and even white dwarfs have densities over a million times less) meaning that a teaspoon of neutron star material would weigh around a billion tonnes.

Neutron stars can also accrete matter from other objects in space. When neutron stars accrete matter they get smaller as the neutron degeneracy pressure grows more intense. Neutron stars do have a similar limit to that of white dwarfs but when they reach their limit they behave quite differently. When neutron stars gain matter and neutron degeneracy pressure is over thrown by gravity, a neutron star can form a black hole.

3. Black Holes (BHs)

Black holes are objects so dense that not even light can escape their gravity, and since nothing can travel faster than light, nothing can escape from inside a black hole. On the other hand, a black hole exerts the same force on something far away from it as any other object of the same mass would do. For example, if our Sun were magically crushed until it was about 6km in size, it would become a black hole, but the Earth would remain in its same orbit.

Fig.3.8 Shows black hole formed at the end of stellar evolution.

Theoretically this is what a black hole would look like but of course we can't see a black hole but we can see how other objects are gravitationally effected

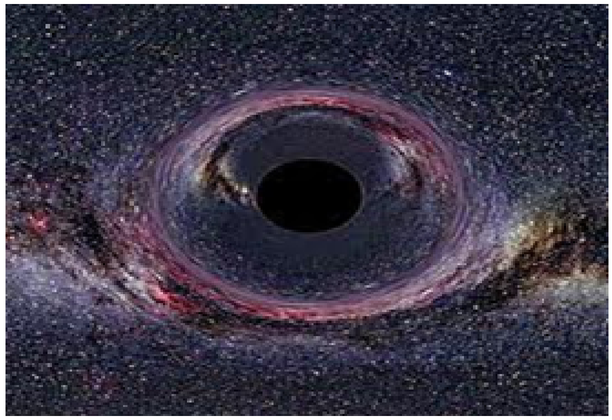

Figure 3.8: Black hole formed at the end of stellar evolution.

by it. Hints the above picture [16].

In general, a black hole is a region of space whose attractive gravitational force is so intense that no matter, light, or communication of any kind can escape. A black hole would thus appear black from the outside. However, gas around a black hole can be very bright. It is believed that black holes form from the collapse of stars. As long as they are emitting heat and light into space, stars are able to support themselves against their own inward gravity with the outward pressure generated by heat from nuclear reactions in their deep interiors. Every star, however, must eventually exhaust its nuclear fuel. When it does so, its unbalanced self-gravitational attraction causes it to collapse. According to theory, if a burned-out star has a mass larger than about twice the mass of our Sun (as a protoneutron star), no amount of additional pressure can stave off total gravitational collapse. The star collapses to form a black hole. For a nonrotating collapsed star, the size of the resulting black hole is proportional to the mass of the parent star; a black hole with a mass three times that of our Sun would have a diameter of about 20km.

Black holes, very massive ones, are found at the center of galaxies. The black hole at the center of the Milky Way is about 4.3 million solar masses. There are many black holes bigger than the one found at the center of the Milky Way and there are also smaller ones. Black holes do not start of very massive (over 8 solar masses), they usually gain matter from objects failing onto them and or they merge with other black holes. Stars can be tidally disrupted by super massive black holes.

Chapter 4

The Study of Population of Compact Objects in Milky-Way Galaxy with Stellar Luminosity and Mass Functions

4.1 Initial Mass Function (IMF)

In astronomy, the initial mass function(IMF) is an empirical function that describes the initial distribution of that of masses for population of stars. The IMF is an output of the process of star formation. The IMF is often given as a probability distribution function (PDF) for the mass at which a star enters the main sequence (begins hydrogen fusion). The distribution function can then be used to construct the mass distribution (the histogram of stellar masses) of a population of stars. It differs from the present day mass function (PDMF), the current distribution of masses of stars, due to the evolution and death of stars which occurs at different masses as well as dynamical mixing in some populations. In general, stellar IMF is the mass function at the formation time.

The properties and evolution of a star are closely related to its mass, so the IMF is an important diagnostic tool for astronomers studying large quantities of stars. For example, the initial mass of a star is the primary factor determining its colour, luminosity, and lifetime. At low masses, the IMF sets the Milky Way Galaxy mass budget and the number of substellar objects that form. At intermediate masses, the IMF controls chemical enrichment of the interstellar medium. At high masses, the IMF sets the number of core collapse supernova that occur and therefore the kinetic energy feedback.

The IMF is relatively invariant from one group of stars to another, though some observations suggest that the IMF is different in different environments [22].

The IMF specifies the fractional distribution in mass of a newly formed stellar system. It is often assumed to have a simple power law:

$$\xi(M) = cM^{-\alpha} \tag{4.1.1}$$

In general, $\xi(M)$ extends from a lower to an upper cutoff, e.g., from 0.1 to 125 solar masses. Commonly used IMFs are those of Salpeter (1955), Scalo (1986), and Miller and Scalo (1979).

4.1.1 Form of the Initial Mass Function (IMF)

The IMF is often stated in terms of a series of power laws, where $N(m)dm$ (sometimes also represented as $\xi(m)\Delta m$), the number of stars with masses in the range m to $m + dm$ within a specified volume of space, is proportional to $m^{-\alpha}$, where α is a dimensionless exponent. The IMF can be inferred from the present day stellar luminosity function by using the stellar mass-luminosity relation together with a model of how the star formation rate varies with time. Commonly used forms of the IMF are the Kroupa (2001)broken power law [15] and the Chabrier (2003) log-normal [5].

1)Salpeter Mass Function

The IMF of stars more massive than our sun was first quantified by Edwin Salpeter in 1955 [21]. His work favoured an exponent of $\alpha = 2.35$. This form of the IMF is called the Salpeter function or a Salpeter IMF. It shows that the number of stars in each mass range decreases rapidly with increasing mass. The Salpeter Initial Mass Function is $\xi(m)\Delta m{=}\xi_0(\frac{m}{M_\odot})^{-2.35}(\frac{\Delta m}{M_\odot})$. Where, $M_\odot$ is the solar mass, and ξ_0 is a constant relating to the local stellar density.

The IMF is generally categorized by a segmented power law or a log-normal type mass distribution (Kroupa, 2001; Chabrier, 2003). For the sake of simplicity, we adopt the power-law formalism of the type:

$$dN \propto m^{-\alpha} dm \tag{4.1.2}$$

but this should not be taken to mean that the IMF needs to be described in such a manner. For clarity, it should be noted that IMFs are also commonly described in terms of a distribution in log mass:

$$dN \propto m^{-\Gamma} d(logm) \tag{4.1.3}$$

,where $\Gamma = -(\alpha - 1)$(Scalo, 1986). The Salpeter (1955) slope for high-mass stars is then $\alpha = 2.35$ or $\Gamma = -1.35$. We also note here that the critical values of $\alpha = 1$, $\Gamma = -1$ occur when equal mass is present in each mass decade (for $1 - 10M_\odot$ and $10 - 100M_\odot$).

- **Note:** $M_\odot \rightarrow$ solar mass is a standard unit of mass in astronomy, equal to approximately $2X10^{30}kg$. It is used to indicate the masses of other stars, as well as clusters, nebulae, and galaxies. It is equal to the mass of the Sun (denoted by the solar symbol $\odot$) ,and $R_\odot = 7X10^{10}cm$.

The Initial Mass Function for stars in the Solar neighborhood was determined by Salpeter in 1955. He obtained:

$$\xi(m) = \xi_0 m^{-2.35} \tag{4.1.4}$$

,where ξ_0=constant which sets the local stellar density.

Using the definition of the IMF, the number of stars that form with masses between M and $m + \Delta m$ is: $\xi(m)\Delta m$. To determine the total number of stars formed with masses between m_1 and m_2 , integrate the IMF between these limits:

$$N = \int_{m_1}^{m_2} \xi(m)dm \tag{4.1.5}$$

$$N = \int_{m_1}^{m_2} \xi(m)dm$$

$$\Rightarrow N = \xi_0 \int_{m_1}^{m_2} m^{-2.35}dm$$

$$\Rightarrow N = \xi_0[\frac{m^{-1.35}}{-1.35}]_1^2 = \frac{\xi_0}{1.35}[m_1^{-1.35} - m_2^{-1.35}]$$

$$\Rightarrow N = \frac{\xi_0}{1.35}[m_1^{-1.35} - m_2^{-1.35}] \tag{4.1.6}$$

We can similarly workout for the total mass in stars born with mass $m_1 < m < m_2$:

$$M_* = \int_{m_1}^{m_2} m\xi(m)dm \tag{4.1.7}$$

Properties of the Salpeter IMF

- Most of the stars (by number) are low mass stars.
- Most of the mass in stars resides in low mass stars.
- Following a burst of star formation, most of the luminosity comes from high mass stars.

Salpeter IMF must fail at low masses, since if we extrapolate to arbitrary low masses the total mass in stars tends to infinity! Observations suggest that the Salpeter form is valid for roughly $m > 0.5M_{sun}$, and that the IMF 'flattens' at lower masses. The exact form of the low mass IMF remains uncertain.Source → ASTRO 3830:Sprin 2004

2)Miller-Scalo

Later authors extended the work below one solar mass ($M_{\odot}$).Glenn E. Miller and John M. Scalo suggested that the IMF "flattened" (approached C below one solar mass [20].

3)Kroupa

Pavel Kroupa kept $\alpha = 2.3$ above half a solar mass, but introduced above half a solar mass, but introduced $\alpha = 1.3$ between $0.08 - 0.5M_{\odot}$.

$$\xi(m) = m^{-\alpha} \tag{4.1.8}$$

$\alpha = 0.3$ for $m < 0.08$,

$\alpha = 1.3$ for $0.08 < m < 0.5$,

$\alpha = 2.3$ for $m > 0.5$.

In general, for ease of description, the IMF is generally given in the form, such as the Kroupa (2001) IMF:

$$dN \propto m^{-2.3}dm, m \geq 0.5M_{\odot}$$

$$dN \propto m^{-1.3}dm, 0.08 \leq m \leq 0.5M_{\odot}$$

$$dN \propto m^{-0.3}dm, m \leq 0.08M_{\odot}$$

4)Chabrier

Chabrier 2003 for individual stars:

$$\xi(m)\Delta m = 0.158(\frac{1}{(ln(10)m)})e^{\frac{[-(log(m)-log(0.08))^2]}{2\times 0.69^2}}, m < 1. \tag{4.1.9}$$

$$\xi(m) = km^{-\alpha}, m > 1 \rightarrow \alpha = \pm 2.3 + 0.3 \quad (4.1.10)$$

Chabrier 2003 for stellar systems (e.g. binaries):

$$\xi(m)\Delta m = 0.086(\frac{1}{(ln(10)m)})e^{\frac{[-(log(m)-log(0.22))^2]}{2\times 0.57^2}}, m < 1. \quad (4.1.11)$$

$$\xi(m) = km^{-\alpha}, m > 1 \rightarrow \alpha = \pm 2.3 + 0.3 \quad (4.1.12)$$

In general, $\xi(m)$ extends from a lower to an upper cutoff, e.g., from 0.1 to 125 solar masses. Commonly used IMFs are those of Salpeter (1955), Scalo (1986), and Miller and Scalo (1979).

Parameters of Salpeter (1955), Scalo (1986) and Miller & Scalo (1979) laws for the IMF: m_1 and m_2 and are the lower and higher mass cutoffs, and is the parameter of the power law. Fig.4.1 Shows the three IMFs used in the spectral evolutionary

Table 4.1: Parameters of Salpeter (1955), Scalo (1986) and Miller & Scalo (1979) laws for the IMF: m_1 and m_2 and are the lower and higher mass cutoffs, and is the parameter of the power law.

IMF	m_1	m_2	α
Salpeter	0.10	125	1.35
Scalo	0.10	0.18	-2.60
	0.18	0.42	0.01
	0.42	0.62	1.75
	0.62	1.18	1.08
	1.18	3.50	2.50
	3.5	125.	1.63
Miller & Scalo	0.10	1.00	0.2
	1.00	2.00	1.00
	2.00	10.0	1.30
	10.0	125.	2.30

models of Bruzual and Charlot (1993).

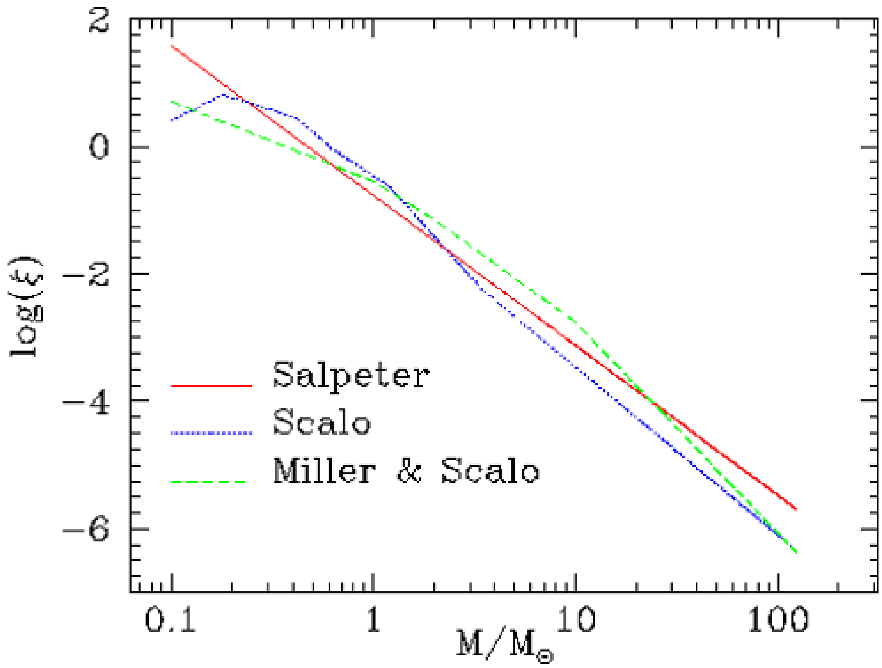

Figure 4.1: The three IMFs used in the spectral evolutionary models of Bruzual and Charlot (1993).

The different slopes of the three considered laws produce different spectral energy distributions: The Scalo and Miller & Scalo laws are flat at small masses and less rich of massive stars with respect to the Salpeter law. The large number of massive stars in the Salpeter law produces an excess of UV flux, whereas the Scalo law generates too many solar mass stars, making the spectrum too red to match the observed colours. We adopted the Miller & Scalo law as a good compromise. We also tested the influence of a change in IMF, finding a negligible effect in photometric redshift computation (Bolzonella et al. 2000).

Determining the IMF is a tricky business

Observed star counts

- Understand your selection effects, completeness
- Get the distances
- Estimate the extinction
- Correct for unresolved binaries

Get the Present-Day Luminosity Function (PDLF)

- Assume the appropriate mass-luminosity relation
- It is a function of metallicity, bandpass,
- Theoretical models tested by observations

Get the Present-Day Mass Function (PDMF)

- Assume some evolutionary tracks, correct for the evolved stars (also a function of metallicity,
- Assume some star formation history

Get the Initial Mass Function (IMF)

4.2 Mass Distribution

In Physics and mechanics, mass distribution is the spatial distribution of mass within a solid body. In principle, it is relevant also for gases or liquids, but on earth their mass distribution is almost homogeneous.

In astronomy mass distribution has decisive influence on the development e.g. of nebulae, stars and planets. The mass distribution of a solid defines its center of gravity and influences its dynamical behavior-e.g. the oscillations and eventual rotation.

The typical mass of field white dwarfs is $\simeq 0.6M_{\odot}$ (Fig. 3.1.). Masses, M and radii, R of the 1833 WDs in the SDSS sample were directly determined from the effective temperature and log g. Given T_{eff} and log g of a star, mass and radius are computed from the definition of the surface gravity:

$$M = \frac{R^2}{G} 10^{logg} \tag{4.2.1}$$

and from the mass-radius relation $M = M(R, T_{eff})$. The resulting mass distribution (Fig.3.1) exhibits both the peak of $0.562M_{\odot}$ and the high mass tail. Fig.4.2 Shows histogram of the mass distribution from the SDSS sample of Kleinman [9].

The peak mass of the SDSS catalog is in excellent agreement with earlier studies, which used much less numerous samples and various methods of white dwarf mass determination (for details, see. [9].)

4.3 Spectral Classification of Compact Objects

4.3.1 Spectral Classification of White Dwarfs

The modern spectral classification of white dwarfs is based on E.M. Sion, J. L. Greenstein, J. D. Landstreet, J. Liebert, H. L. Shipman & G. A. Wegner, ApJ, 269, 253 (1983) and, according to Shipman, worked out in the old Bartol Conference room in Sharp Lab.

The class D is used for white dwarfs. Class D is further divided into sub-classes DA, DB, DC, DO, DZ, and DQ. The letters are not related to the letters used in

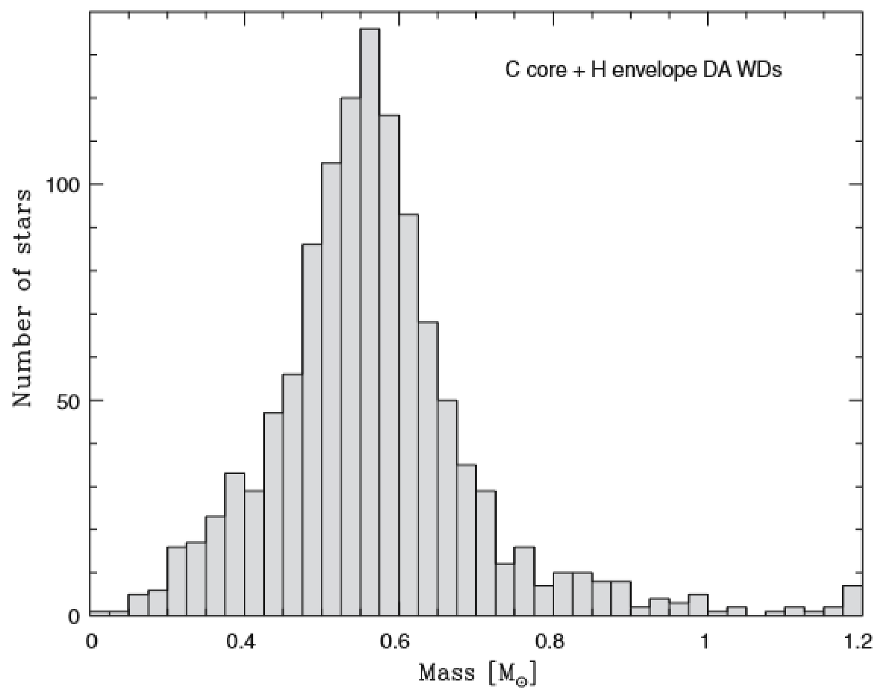

Figure 4.2: Histogram of the mass distribution from the SDSS sample of Kleinman [9].

the classification of non-degenerate stars, but instead indicate the composition of the white dwarf's outer layer or "atmosphere". Optical spectra of white dwarfs have been classified according to their dominant element in the atmosphere. The white dwarf classes are:

- DA: strong hydrogen lines → a hydrogen-rich "atmosphere" or outer layer, indicated by strong Balmer hydrogen spectral lines.
- DB: strong He I lines → a neutral helium-rich "atmosphere" or outer layer, indicated by neutral helium spectral lines, (He I lines).
- DO: strong He II lines → an ionized helium-rich "atmosphere" or outer layer, indicated by ionized helium spectral lines, (He II lines).

- DC: no strong lines (continuous) spectrum → Featureless continuum with no strong spectral lines.
- DZ: strong metal lines (excluding carbon) → Presence of spectral lines of heavy elements, indicated by calcium, magnesium,and/or iron lines, (Ca I, Ca II H and K, Mg I, Fe I, Na I).
- DQ: strong carbon lines → Presence of atomic or molecular carbon lines.
- DX → spectral lines are insufficiently clear to classify into one of the above categories.

All class D stars use the same sequence from 0 to 9, with 1 indicating a temperature above $37,500K$ and 9 indicating a temperature below 5,500 K. (The number is by definition equal to $50,400K/T_{eff}$.)

The white dwarf classification is extended to allow for 'hybrids':

- DAB: Spectrum shows lines of hydrogen and neutral helium, with the H lines stronger than the He. Only one or two are known.
- DBA: Spectrum shows lines of hydrogen and neutral helium, with the H lines weaker than the He.
- DAO: Spectrum shows lines of hydrogen- and ionized helium-rich white dwarf, with the H lines stronger than the He.
- DAZ: a hydrogen-rich cool metallic white dwarf.
- DBZ: a helium-rich cool metallic white dwarf.

Multiple families are shown in decreasing order, e.g. DAB, DQAB.

4.3.2 White Dwarf Search

All galaxy surveys will also provide a set of WDs. Kleinman et al. [10] have published a catalog of spectroscopically identified WDs in the first data release of the Sloan Digital Sky Survey. The Sloan Digital Sky Survey (SDSS) is a continuing imaging and spectroscopic survey of some $7-10$ thousand square degrees in the north Galactic cap. Though its main focus is extragalactic, there are many Galactic spin-off projects resulting from the survey. In an area which is 1400 square degrees, they find 2551 white dwarf stars of various types and an additional 144 objects as uncertain white dwarf stars. Of all white dwarf stars, 1888 are nonmagnetic DA types and 171 non-magnetic DBs. The remaining 492 objects consist of all different types: DO, DQ, DC, DZ and hybrid stars. The DA and DB spectra are fitted with a grid of atmospheric models to determine T_{eff} and log g for each object (Fig.3.3). This catalog nearly doubles the known sample of spectroscopically identified white dwarf stars. Fig.4.3 Shows white dwarf stars found in the SDSS with spectra fitted to atmospheric models. Left: distribution in effective temperature for DAs (top) and DBs (bottom); right: distribution in log g for the same types. Figure adapted from Kleinman et al. [10].

4.3.3 White Dwarf Stars - Observational Material

The position in color - magnitude diagrams

We begin by considering the position of white dwarfs' stars in Color - Magnitude diagrams (CMD). The brightness of stars is usually measured on the magnitude scale (which originated with the ancient Greek astronomer Hipparchus). The apparent magnitude,m,of a star is related to the measured flux,f, in a particular wavelength

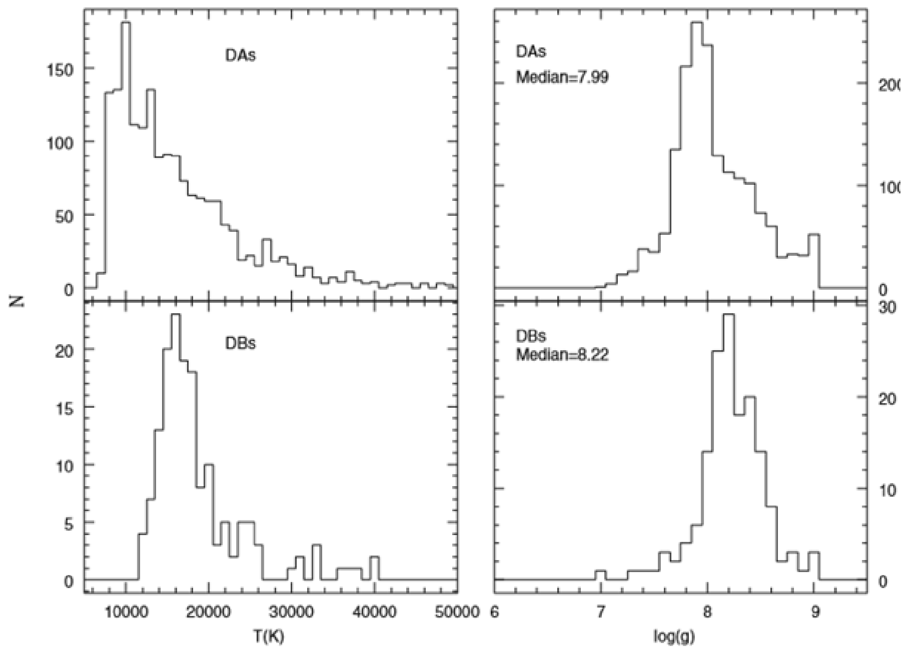

Figure 4.3: White dwarf stars found in the SDSS with spectra fitted to atmospheric models. Left:distribution in effective temperature for DAs (top) and DBs (bottom); right: distribution in log g for the same types. Figure adapted from Kleinman et al.[10]

interval (or band)by:

$$m = -2.5log\frac{f}{f_0} \tag{4.3.1}$$

,where f_0 is a constant specific to the particular band. Clearly f_0 is equal to the flux of a star of zero magnitude. The absolute magnitude,M,of a star is defined to be the magnitude it would have if it were at a distance of 10 parsecs (pc), and there was no interstellar extinction. This is related to m and d,the distance to the star in pc, by:

$$M = m + 5 - 5logd - A \tag{4.3.2}$$

,where A is the correction for interstellar extinction in magnitudes.

The bolometric magnitude is a measure of the total radiation from the star emitted over all wavelengths. The luminosity of a star is the total energy emitted (in electromagnetic radiation) in unit time. The luminosity,L of a star and it absolute bolometric magnitude,M_{bol} are related by:

$$M_{bol} = 4.75 - 2.5log\frac{L}{L_{\odot}} \tag{4.3.3}$$

, where $L_{\odot}$ is the luminosity of the Sun. A recent measurement of the solar luminosity is $3.8515 \times 10^{33} ergs^{-1}$.

A difference between two magnitudes is called a **color index** or simply a **color**. The two colors in the UBV system are U-B and B-V. A plot of one color against another for a set of stars is called a two color diagram. A plot of a color against magnitude for a set of stars is called a **color - magnitude diagram** (CMD). Plotting color against apparent magnitude is not very useful unless we have reason to believe that all the stars in the sample are at the same distance.

The physical significance of a color is that it is a measure of the temperature of the radiating surface. A cool piece of iron, e.g. at room temperature, emits radiation at infra-red wavelengths with peak emission at about $10\mu m$. If we heat the iron to about $1000K$, it will glow a dull red. If we continue to increase the temperature, if will first glow at a lighter red, then yellow, with peak emission shifting to shorter wavelengths. Although the surfaces of stars are usually mainly hydrogen gas or plasma, there is a similar qualitative relation between color and temperature. A cool star will emit more radiation in the V band than in the B band and hence B-V will be positive. A hot star will emit more radiation in the B band than in the V band and hence B-V will be negative.

Because stars vary in other ways than surface temperature (e.g. surface gravity and composition), there is not a unique correspondence between a single color and temperature. Much of the degeneracy can be removed by considering two (or more) colors.

Color - Magnitude diagrams will only be useful if the stars are at the same distance (or if the distances of the stars are known). For clusters of stars it is reasonable to assume that all the stars in the cluster are essentially at the same distance. It is also usually assumed that the stars all formed from a single gas cloud and hence have the same age and composition.

Fig.3.4 is a plot of the absolute visual magnitude of a sample of stars in the globular cluster M55 against their B-V color, which is the difference between the magnitude measured using a B (blue) filter and that measured using a V (visual) filter. (The B and V filters are broad filters centered approximately at wavelengths of 440 and 550nm, respectively). It can be seen that most of the stars lie close to a diagonal line in the lower right of the diagram. This is termed the Main Sequence. Stars that lie near the diagonal line in the upper right of the diagram are on the Red Giant Branch. They are called giants because an application of Stefan's Law for a black body shows that they have radii much larger than Main Sequence stars of similar temperature. Fig.4.4 Shows M55 globular cluster Color-Magnitude diagram.Credit: B.J.Mochejska, J. Kaluzny (CAMK), 1m Swope Telescope. Fig.4.5 Shows Color - Magnitude diagram for the globular cluster M4, showing the location of white dwarf stars. From Richer et al. 1995, ApJ, 451, L17

Figure 3.5 shows color - magnitude diagrams for the globular cluster M4. Below the Main Sequence we now can see an almost parallel sequence of hot blue stars. Again Stefan's law can be used to show that these stars are much smaller than Main Sequence stars of similar temperature. These stars are the white dwarfs.

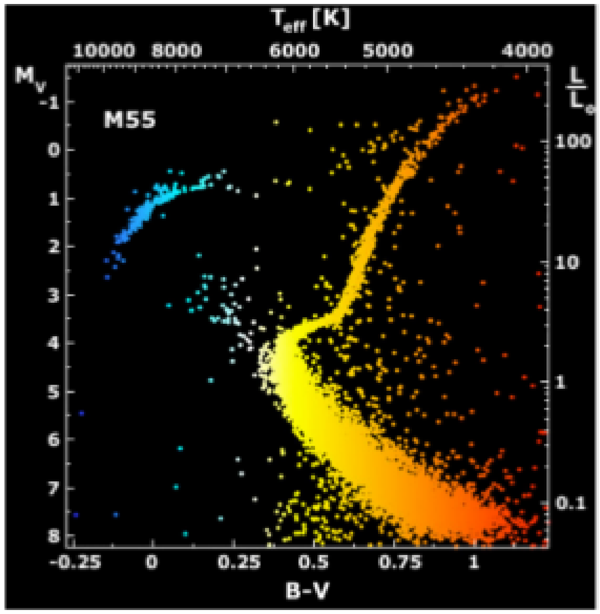

Figure 4.4: M55 globular cluster Color-Magnitude diagram.Credit: B.J. Mochejska, J. Kaluzny (CAMK), 1m Swope Telescope.

4.3.4 WDs in Solar Neighborhood

Recently, a sample of white dwarfs has been selected from SDSS DR3 imaging data using their reduced proper motions, based on improved proper motions from SDSS plus USNO-B combined data. Numerous SDSS and follow up spectra are used to quantify completeness and contamination of the sample; kinematic models are used to understand and correct for velocity-dependent selection biases. A luminosity function is constructed covering the range $7 < M_{bol} < 16$ (Fig.3.6). Fig.4.6 Shows the luminosity function of local white dwarfs derived from the SDSS survey. The numbers indicate the numbers of stars for each data point. The dashed line at the bright end is from Liebert et al.[18], based on the analysis from the PG Survey, including DA WDs only.

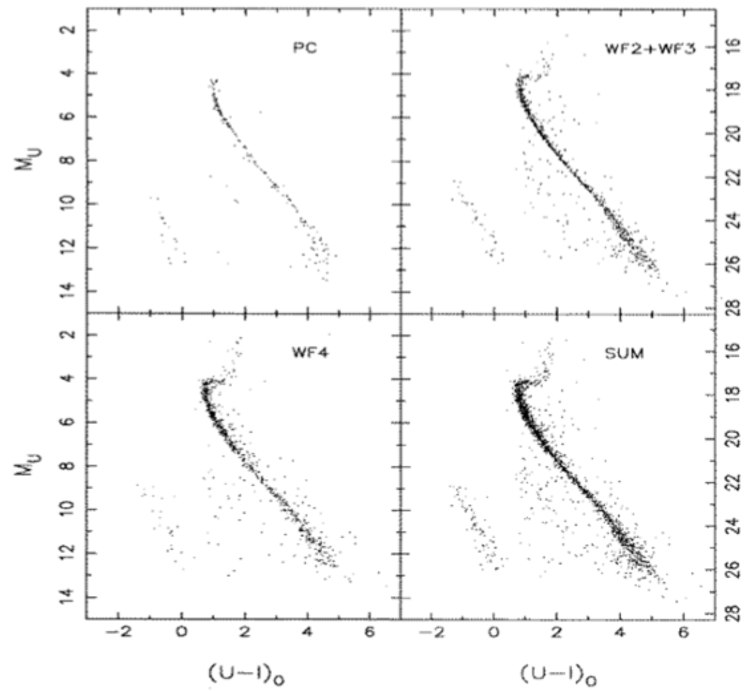

Figure 4.5: Color - Magnitude diagram for the globular cluster M4, showing the location of white dwarf stars. From Richer et al. 1995, ApJ, 451, L17

4.3.5 White Dwarf Populations in Distant Clusters

To study faint white dwarf populations in distant systems such as open and globular clusters, one often has to deal with what could be called "minimal" or two-band photometry that produces a single color-magnitude diagram (CMD). Cooling theory can be used in conjunction with model atmospheres to compute the evolutionary tracks and plot isochrones in the CMD. However, the photometric scatter in such CMD's is generally large for white dwarfs and only qualitative results can be obtained from the direct comparison of isochrones with observational points in the CMD's. Clearly, the proper way to exploit the information contained in these diagrams is through actual stellar counts and the construction of observed luminosity functions.

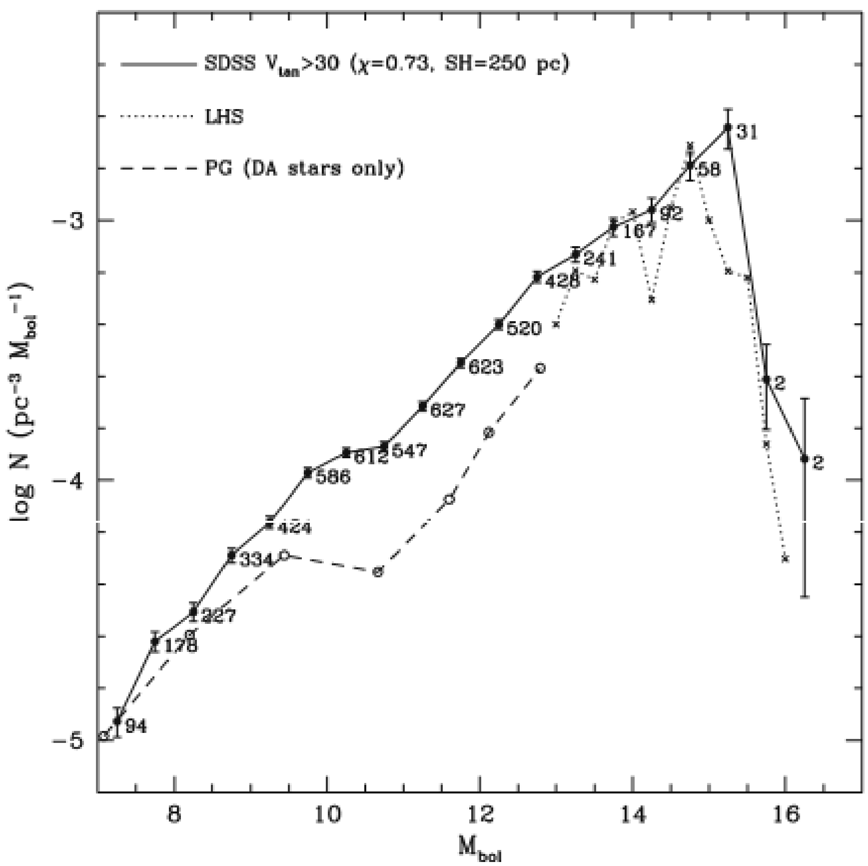

Figure 4.6: The luminosity function of local white dwarfs derived from the SDSS survey. The numbers indicate the numbers of stars for each data point. The dashed line at the bright end is from Liebert et al. [26], based on the analysis from the PG Survey, including DA WDs only.

4.4 Observational constraints

Fundamental properties of a star include the mass M (usually expressed in units of the solar mass, $M_{\odot} = 1.99X10^{33}$), the radius R (often expressed in $R_{\odot} = 6.96X10^{10}cm$), and the luminosity L, the rate at which the star radiates energy into space (often expressed in $L_{\odot} = 3.84X10^{33}erg/s$).

4.4.1 Mass-luminosity and mass-radius relation

For stars with measured masses, radii and luminosities (i.e. binary stars) we can plot these quantities against each other. These quantities are clearly correlated, and especially the relation between mass and luminosity is very tight. The observed relations can be approximated reasonably well by power laws:

$$L \propto M^{3.8} \tag{4.4.1}$$

and

$$R \propto M^{0.7}. \tag{4.4.2}$$

Again, the theory of stellar evolution must explain the existence and slopes of these relations.

4.5 Basic assumptions

We wish to build a theory of stellar evolution to explain the observational constraints highlighted above. In order to do so we must make some basic assumptions:

- stars are considered to be *isolated* in space,so that their structure and evolution depend only on intrinsic properties (mass and composition). For most single stars in the Galaxy this condition is satisfied to a high degree (compare for instance the radius of the Sun with the distance to its nearest neighbour Proxima Centauri). However, for stars in dense clusters, or in binary systems, the evolution can be influenced by interaction with neighbouring stars. In this course we will mostly ignore these complicating effects.

- stars are formed with a *homogeneous composition*, a reasonable assumption since the molecular clouds out of which they form are well-mixed. We will often assume a so-called quasi-solar composition (X = 0.70, Y = 0.28 and Z = 0.02), even though recent determinations of solar abundances have revised the solar metallicity down to Z = 0.013. In practice there is relatively little variation in composition from star to star, so that the initial mass is the most important parameter that determines the evolution of a star. The composition, in particular the metallicity Z, is of secondary influence but can have important effects especially in very metal-poor stars.

- *spherical symmetry*, which is promoted by self-gravity and is a good approximation for most stars. Deviations from spherical symmetry can arise if non-central forces become important relative to gravity, in particular rotation and magnetic fields. Although many stars are observed to have magnetic fields, the field strength (even in highly magnetized neutron stars) is always negligible compared to gravity. Rotation can be more important, and the rotation rate can be considered an additional parameter (besides mass and composition) determining the structure and evolution of a star. For the majority of stars (e.g. the Sun) the forces involved are small compared to gravity. However, some rapidly rotating stars are seen (by means of interferometry) to be substantially flattened.

Chapter 5

Result and Discussion

By now we have a handful of theoretical models that are trying to address the population scenario of compact objects in galaxies. To this end, observationally the Milky-Way galaxy, is a preferred galaxy as the proximate galaxy.

Simplifying assumptions and boundary conditions

a) We assume the mean core as the center of the formation with spherical symmetry.

b) Initial luminosity complex function assumes pre-compact formation history and material density decreasing radially outward from the core.

c) The number of stars vs initial mass function is that of the Salpeter et. al.

Applying these conditions:

i) using eqn. we obtain the result as depicted in fig. 5.1.

From the plot we observe that the population of the compact objects fall with distance from the center of the galaxy. This is in good agreement with the stellar evolutionary history theory.

However, the models are constructed to guess after guess with fitting purposes.

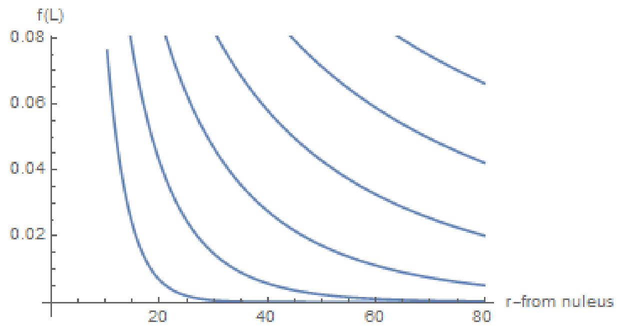

Figure 5.1: New Compact object population vs radial distance

So we cannot conclusively draw a complete theory of current models. They need further research and developments. Yet they are good enough to extract approximately relevant data to explain the true nature.

ii) Using the number density of initial mass function versus the initial mass relation equation we obtain the result whose plot is depicted as in 5.2.

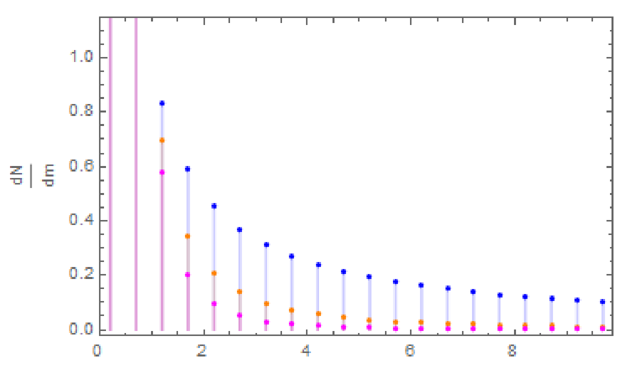

Figure 5.2: Compact object number density of initial mass function vs the initial mass

Here as we observe from the plot, the number of compact stars formed is inversely proportional to the initial mass. This shows that the number of stars in each mass range decreases rapidly with increasing mass. Also,the properties and evolution of a star are closely related to its mass.

According to our current understanding, the primary parameter that determines the final fate of a star is its mass at birth.

The Hertzsprung-Russell(HR) diagrams of star clusters are particularly important for the stellar evolution.

Chapter 6

Summary and Conclusion

Comparing result where we adopted the oversimplified boundary condition we obtained a result that reasonably agrees with the current theory in cluding the observational result extracted from the Sloan Digital Sky Survey (SDSS). But this indicates indirectly that the existing theory by itself is an oversimplified one which needs further development.

The mass distributions, orbital properties and/ or proper motion of the COs can inform us on stellar evolution and explosion mechanisms. A dead galaxy does not mean it has stopped forming stars. Each star depending on its initial mass will either end up as a white dwarf, neutron star, or black hole. Stars born with mass $M < 8M_{\odot}$ evolve into white dwarfs (WD), those of $M \simeq 8 - 20M_{\odot}$ evolve into neutron stars (NS), and those above $20M_{\odot}$ turn into black holes, though stars between $M \simeq 120 - 250M_{\odot}$ may undergo a pair instability supernova that leaves no remnant.

Stars form immense groups called galaxies.The Milky-Way Galaxy is a spiral galaxy in which the sun is but one of billions of stars.

Compact objects are not equally distributed near and away from the center of MW

Galaxy. The localization of COs within a galaxy may also be indicative of the progenitor's formation conditions.

White dwarf stars, compact objects with extremely high interior densities, are the most common end product in the evolution of stars. The evolution towards white dwarfs is the dominant channel in galaxies, which determines the evolution and final fate of most of their mass.

A gaggle of black holes has been found clustered around the center of our home galaxy, the Milky Way and the discovery hints at a much larger population of black holes hidden across the galaxy. Black holes, very massive ones, are found at the center of galaxies. The black hole at the center of the Milky Way is about 4.3 million solar masses. There are many black holes bigger than the one found at the center of the Milky Way and there are also smaller ones. The current ($z = 0$) population of BHs is particularly important as BHs evolve from the most massive stars, whose short lives mean that we can only directly observe the population that formed within the last 20 Myr. Similarly, there have been no firm detections of stellar mass BHs without a stellar companion in the MW. Such black holes are not expected to emit electromagnetic radiation unless they are accreting from a dense environment.

Using sky server search form, we have searched for objects of different magnitudes by specifying upper and lower limits in each wave length filter (u,g,r,i,z) from observation, provided internationally from Sloan Digital Sky Servey (SDSS). The SDSS addresses fascinating, fundamental questions about the universe. The Sloan Digital Sky Servey (SDSS) will tell us which theories are right-or whether we will have to come up with entirely new ideas.

In astronomy, the initial mass function(IMF) is an empirical function that describes the initial distribution of that of masses for population of stars. The distribution function can then be used to construct the mass distribution (the histogram of stellar masses) of a population of stars. It is the mass function at the formation time. The properties and evolution of a star are closely related to its mass, so the IMF is an important diagnostic tool for astronomers studying large quantities of stars. For example, the initial mass of a star is the primary factor determining its colour, luminosity, and lifetime. Following a burst of star formation, most of the luminosity comes from high mass stars. The IMF is often stated in terms of a series of power laws.

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